Modelling water-use of irrigated forage systems in northern Victoria

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Abstract
The dairy industry in northern Victoria relies on irrigation water to grow a large proportion of its feed. Over the last 15 years, irrigation allocations have been substantially lower and more variable than for the preceding 20-30 years. This has caused dairy farmers to change their feedbase and has made it difficult for them to plan their forage mix. A study was conducted to determine the annual irrigation water requirements for five irrigated forages at three locations in northern Victoria; Kerang, Kyabram and Yarrawonga. The FAO-56 model was used to estimate the irrigation water requirements of the forages using 70 years of historical weather data. These estimates were then compared to measured irrigation water-use from field experiments based near Kyabram, and the model parameters adjusted if necessary to ensure consistency of modelled and measured water requirements. Modelled mean annual irrigation water-use, across the three locations, was highest for the perennial pasture (9.1 ML/ha) and lucerne (8.7 ML/ha), intermediate for maize (6.0 ML/ha) and long-season annual pasture (5.3 ML/ha), and lowest for the short-season annual pasture (3.2 ML/ha). The range in water-use for maize at each location was smaller than that of the other forage types. Annual irrigation water-use for all crop types was higher at Kerang than at either Kyabram or Yarrawonga. The large range in annual irrigation water-use meant that for planning purposes, the probability of exceedance values were a better descriptor of the amount of irrigation water required than a simple average (and range). These data will be useful to dairy farmers who are planning their management responses to limited availability of irrigation water.

Key Words
water requirements, perennial pasture, annual pasture, maize, lucerne

Introduction
The dairy industry in northern Victoria relies on irrigation water to grow a large proportion of its feed inputs. The irrigation water requirements of perennial pastures in northern Victoria are typically 8 ML/ha (Armstrong et al. 2000), while winter-growing annual pastures require 3-6 ML/ha (Stockdale 1986). However, plant water requirements, especially irrigation requirements, can vary markedly from year to year due to seasonal conditions. For example, irrigation water applied to maize grown on two commercial farms varied between a typical 6.3 ML/ha in 2003/04 to 3.8-4.8 ML/ha in the cooler, wetter summer of 2004/05 (Greenwood et al. 2008). In 2006, irrigation water applied to perennial pastures was 12.0 ML/ha, compared with 8.2 ML/ha in 2005 (Lawson et al. 2009). Increases in irrigation water requirements in dry years are not only due to lower rainfall, but also higher evaporative demand (Greenwood et al. 2009).

The FAO-56 model (Allen et al. 1998) can be used to predict the water requirements of irrigated forages using climatic data (Allen 2000; Allen et al. 2005; Sau et al. 2005). The model and input parameters have been validated for northern Victorian conditions, with good agreement between measured and modelled soil water deficits for most pastures (Greenwood et al. 2009). Therefore, the FAO-56 model can be confidently used to predict the total and irrigation water requirements of typical irrigated forages grown in northern Victoria. These data will be useful to dairy farmers in planning their management responses to limited availability of irrigation water.

The objective of this study was to determine the probability distribution of annual water requirements of five irrigated forages at three locations in northern Victoria.

Methodology
Crop irrigation water requirements were modelled on a daily basis for five forage types at three locations in northern Victoria using 70 years of climate data.

Simplification of validated, dual crop coefficient model
The FAO-56 model (Allen et al. 1998) offers two options for estimating crop water requirements from climatic data. The dual crop coefficient model was validated for a range of forages in northern Victoria by

Greenwood et al. (2008, 2009). However, the simpler, single crop coefficient model was more appropriate for this long-term modelling project as actual dates of irrigation and defoliation were not known.

For each of the forages modelled, a range of single crop coefficient values were tested in 0.05 increments. The crop coefficient values were selected to ensure that the modelled annual irrigation water-use was the same as that measured by Greenwood et al. (2008 and 2009). The selected crop coefficient value was 1.0 for all the perennial and winter growing annual forages. This value was within the range suggested by Allen et al. (1998). Values of crop coefficient for maize were; 0.3 from pre-irrigation to 20 days after sowing, a linear increase over the next 40 days to 1.2, and 1.2 for the remainder of the production period (Greenwood et al. 2008).

Selection of climatic data

Historical climatic data for Kyabram, Kerang and Yarrawonga were sourced from the SILO website (SILO 2011) for the period 1935 to 2005. The SILO database predictions of reference crop evapotranspiration (ET_o) assume a wind speed of 2 m/s at 2 m height. This assumption generally underestimates values of ET_o in spring, summer and autumn and potentially overestimates ET_o in winter. After checking wind speeds for the Kyabram site, some years followed the suggested trends while other years did not, hence the SILO based ET_o estimates have not been scaled for this modelling exercise.

Selection of forage species

The forages selected were used by either Greenwood et al. (2008, perennial pasture [perennial ryegrass (*Lolium perenne*)-white clover (*Trifolium repens*)], lucerne (*Medicago sativa*), long-season annual pasture [Persian clover (*Trifolium resupinatum*)-Italian ryegrass (*Lolium multiflorum*)] and short-season annual pasture [subterranean clover (*Trifolium subterraneum*)-Italian ryegrass]) or Greenwood et al. [2009, maize (*Zea mays*)].

Irrigation scheduling rules

Irrigation scheduling was on the basis of cumulative ET_o less rainfall (ET_o-R) since the last irrigation or runoff event. No forages were irrigated between 15 May (or 15 April for lucerne) and 15 August. Other irrigation scheduling rules were;

- perennial pasture, irrigated when cumulative ET_o-R >45 mm
- lucerne, irrigated when cumulative ET_o-R >75 mm
- maize (pre-irrigated 15 November, sown 22 November, 110 day growing season, last irrigation 22 March), irrigation when cumulative ET_o-R >60 mm, and
- annual pastures, irrigated when cumulative ET_o-R >45 mm.
    - Short-season (irrigated from 15 March–before 20 October).
    - Long-season (irrigated from 15 February–before 20 November).

Modelling "rules"

The modelling rules assumed;

- all forages were border-check irrigated with irrigation water-use equivalent to the calculated soil water deficit plus 5 mm of ponded surface water (as per Greenwood et al. 2009),
- delay of irrigation if rainfall greater than 10 mm occurred less than 2 days after irrigation,
- no irrigation water left the farm as all irrigation run-off water was captured and reused,
- no collection and storage of winter run-off,
- water intake at the initial autumn irrigation for the annual pastures was derived from cumulative ET_o-R since the last irrigation using a modified version of the relationship presented by Lawson et al. (2009),
- water intake at the initial irrigation of maize was set at 0.8 ML/ha, and
- deep drainage of 1 mm per day each time estimated soil water deficits indicated surface ponding.

Results and Discussion

Rainfall declined and ET_o increased from Kyabram to Kerang, resulting in the difference between average annual ET_o and rainfall increasing from 745 mm at Kyabram to 920 mm at Kerang (Table 1). These geographic effects were also evident in modelled irrigation water-use for all crop types. The average intake of water at Kyabram (excluding the initial irrigation of the annual species) was 52, 83 and 68 mm/irrigation for the pastures, lucerne and maize, respectfully. Modelled annual irrigation water-use of perennial pasture was 9.1 ML/ha when averaged over the three locations. For the other forages average irrigation water-use was 8.7, 6.0, 5.3 and 3.2 ML/ha/year for lucerne, maize, long-season annual and short-season annual, respectfully.

Table 1. Average climatic data (1935-2005) and modelled irrigation water-use (ML/ha/year) for sites in northern Victoria. Absolute range of the data are presented in brackets.

Site	Rainfall (mm)	ET_o (mm)	Perennial pasture	Lucerne	Maize	Long-season annual	Short-season annual
Yarrawonga	517 (239-1068)	1259 (1110-1423)	8.7 (5.2-12.0)	8.3 (4.9-12.0)	5.9 (4.2-7.7)	5.0 (1.9-7.5)	2.9 (0.7-5.0)
Kyabram	453 (199-798)	1198 (1081-1357)	8.6 (5.2-11.6)	8.2 (4.1-12.8)	5.8 (3.5-7.0)	4.9 (1.9-7.2)	2.9 (0.6-4.9)
Kerang	382 (158-758)	1304 (1171-1430)	10.0 (6.3-12.6)	9.6 (5.8-13.1)	6.2 (4.8-7.7)	6.0 (3.3-8.0)	3.7 (1.5-5.8)

Probability of exceedance curves for irrigation water-use are shown in Figure 1. These curves show the proportion of years (Y-axis) for which the irrigation water-use will exceed a certain level (X-axis). For example, annual irrigation water-use for perennial pastures at Kyabram will exceed approximately 5.2, 6.9, 8.6 and 10.2 ML/ha for 99, 90, 50 and 10% of years, respectively. Consequently, annual irrigation water-use for perennial pastures at Kyabram is between 6.9 and 10.2 ML/ha for 80% of years, with water-use falling below this range for 10% of years and above this range for 10% of years. These probability of exceedance values are likely to be of more use for planning purposes than the averages (and ranges) shown in Table 1.

Some interesting features of the curves in Figure 1 are;

- for all forage types there was little difference in irrigation water-use between Kyabram and Yarrawonga, as both rainfall and ET_o are slightly higher at Yarrawonga than at Kyabram,
- the lucerne required a little less irrigation water than the perennial pasture due to the earlier finish to its irrigation season (mid April rather than mid May),
- the curves for lucerne and maize were very “stepwise” compared to those for both the annual and perennial pastures due to their longer irrigation intervals (83 or 68 mm cf. 52 mm), and
- the curves for the maize were very steep compared to the other forages as its growing season rainfall typically comprised a smaller fraction of its total water requirements than that of the other forages.

Modelled estimates for deep drainage at Kyabram were: perennial pasture 32 mm (range 16-75 mm), lucerne 19 mm (5-67 mm), maize (no estimates were made due to the likelihood of double cropping), long-season annuals 27 mm (10-68 mm), and short-season annuals 22 mm (6-60 mm). These values were comparable to published estimates of discharge to the deep aquifer in the Goulburn Valley (Bethune 2004; Greenwood et al. 2009).

Conclusion

Modelled annual irrigation water-use was closely related to the length of the growing season and was highest for perennial pasture and lucerne, intermediate for maize and long-season annual pasture, and lowest for short-season annual pasture. Annual irrigation water-use for all crop types was higher at Kerang than at either Kyabram or Yarrawonga. The large range in annual irrigation water-use meant that for planning purposes, the probability of exceedance values were a better descriptor of the amount of irrigation water required than a simple average (and range). These data will be useful to dairy farmers who are planning their responses to limited availability of irrigation water.

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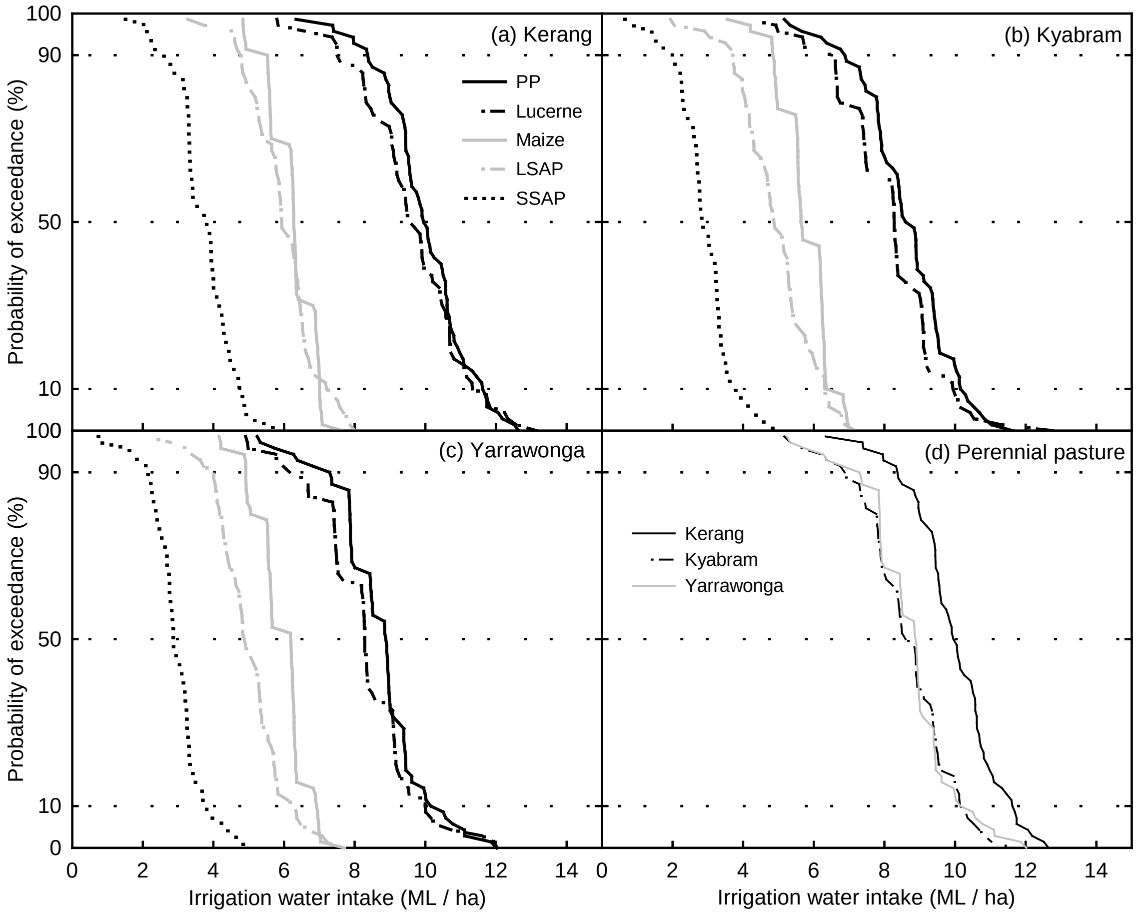

Figure 1. Modelled irrigation water-use of five forage types at (a) Kerang, (b) Kyabram, and (c) Yarrawonga, and (d) a comparison of perennial pasture at three locations, for 1935-2005. The forage types are perennial pasture (PP), lucerne, maize, long-season annual pasture (LSAP) and short-season annual pasture (SSAP).

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